SEGments

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Cover Photo: Janet Furler and her father SEG President Richard Willing on *Minnawarra*. Photograph courtesy of Brad Fleet, The Advertiser.

Rear Cover Photo: *W*estern pygmy possum (*Cercartetus concinnus)* at Innes. Photograph Olly Cirocco.

The Scientific Expedition Group is a not-for profit organisation which began in 1984. SEG undertakes several expeditions each year to record scientific information on wildlife and the environment in many parts of South Australia.

A major expedition to conduct a biodiversity survey occurs each year over two weeks. Scientific experts lead volunteers in surveying mammals, reptiles, invertebrates, vegetation, birds and physical geography. The data collected on each survey are archived with the relevant State scientific institutions to ensure they are available to anyone interested in our State's environment.

In addition to the major expedition, a number of trips for the Vulkathunha-Gammon Ranges Scientific Project are organised annually. A long term study of rainfall on the ranges and of water flow in arid-zone creeks is undertaken. All data are supplied to the Department of Environment Water and Natural Resources and to the Bureau of Meteorology and are available for analysis.

SEG conducts four-day biodiversity surveys at eight different sites each autumn and spring in the Heritage Area of scrub on "Minnawarra" farm near Myponga. Data collected are entered into the Biological Data Base of SA. SEG also conducts annual mallee-fowl monitoring over a weekend in the Murraylands.

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GUEST EDITORIAL

A Native Vegetation Heritage Agreement (HA) in South Australia is a legal document about a conservation area on private land between the Landholder and Minister of Environment and Water, on the recommendation of the Native Vegetation Council. Started in 1980, Native Vegetation Heritage Agreements have been taken up by more than 2000 landholders conserving more than 1 million hectares of scrub in perpetuity.

"Minnawarra", the Willing Family farm on the Fleurieu Peninsula has a HA of 120 ha of scrub, the original application made in 1980. It was thwarted by a bushfire in January 1981 which burnt most of the scrub, leaving nothing for the botanist who came to survey it. Delays set in, with a suspicion that the file sat in a drawer for a few years. It was all signed and delivered in the 1990's. "Minnawarra" contains high quality scrub, much of which has never been grazed. Small grants of a few thousand dollars helped with weed control, fence repairs and fox baiting, but disappeared over the past decade. In November the Environment Minister David Speirs announced that 3 million dollars over 2 years would support HA maintenance again– great news for native vegetation and landholders!

During fencing of the HA we wondered what happened to the plants and animals in this scrub without domestic animals grazing. So was born the monitoring project known as the Minnawarra Biodiversity Project (MBP). The SEG Management Committee approved the plan and the small SEG group which had been surveying the biodiversity of Fleurieu Peninsula road reserves for 3 years transferred their equipment and expertise to the HA as a long-term monitoring project in 2000. Eight sites were set up in the scrub, each with 6 pitfalls, 15 Elliott and 2 cage traps. Over time methods have been upgraded. Buckets have been replaced by 150mm pipe as pits; ear notching for identification has been replaced by microchips; and wildlife cameras used. A strong suspicion of the presence of "Dieback" *(Phytophthora cinnamomi)* at Site 6 closed it, and Site 9 opened. Richard, reluctantly having passed middle age, approves of daughter Janet Furler being the main driver of the surveys now.

We have become much more aware of how changes in season affect not only our farm animals, but also the wildlife in the scrub. The bulk of our mammal captures are Bush rats *(Rattus fuscipes),* Swamp rats *(Rattus lutreolus),* and Antechinus *(Antechinus flavipes).* They indicate a significant growth in populations with 200 to 300 captures and recaptures possible during a busy survey. Numbers are influenced by factors like seasonal variations, temperature changes, rainfall and moonlight. Skinks do not appear in the cold, nor frogs in the dry. It raises questions about why one group is more abundant than the others on different surveys. During the drought 10 years ago there were hardly any animals in traps, but still present in refuge areas. We may well have been going long enough to detect climate change phenomena. There are a lot of data to be sorted out. One of the important outcomes of MBP is that we now have a small group of competent young people trained in handling and microchipping small animals, education being one of the aims of SEG.

Over the years many experts have visited the scrub. We have tried to follow along and absorb their wisdom. Botanists have pointed out many rare Mt Lofty Speedwell plants *(Derwentia derwentiana),* and *Correa aemula* (a threatened species, even though we have a lot!), various orchids and a very southerly stand of Candlebarks (*Eucalyptus dalrympleana)*, one just getting to mature height in the fenced off scrub after 20 years. An entomologist from USA found a rare beetle (*Acanthaferonia ferox*) at midnight, after a week of searching in Mt Compass swamps. He then put her (yes he could tell!) in a test tube of alcohol. A recent bird survey found Lewin's Rail (*Rallus pectoralis)*, a first sighting at Minnawarra. Water rat/Rakali (*Hydromys chrysogaster*) and Rosenberg's goanna *(Varanus rosenbergi)* are rare sightings. During surveys we have caught bandicoots (*Isoodon obesulus*), Western pygmy possums (*Cercartetus concinnus*), and various microbats (identified to species by the presence of a notch in the second tooth – hooray for young eyes!).

Dr Richard Willing
President, Scientific Expedition Group

SOUTHERN AUSTRALIAN VEGETATION – ONE OF THE GREAT NATURAL CLIMATE CHANGE EXPERIMENTS

Professor Bob Hill

South Australia today is characterised by arid and semi-arid vegetation, with a relatively thin strip of more reliable rainfall along some of the central and south-eastern margin where eucalypt forests are common. The arable area for cropping is delineated by Goyder's Line, which lies at the 250 mm rainfall boundary. South of this line the rainfall is generally reliable for cropping; north of it, grazing predominates. Recently it has become clear that climate change is moving the position of Goyder's Line southwards reducing the amount of land in South Australia available for cropping. But South Australia has had a long and dramatic history of climate and associated vegetation change, and over the course of about 45 million years, through one of the great series of natural climate changes, the vegetation has shifted from what was effectively a tropical rainforest to take its current form. The following brief summary outlines the major changes that took place and why they happened.

Forty five million years ago, Australia was connected to Antarctica via the South Tasman Rise, which extended south of Tasmania and provided a firm land connection. At this time Australia was about 20° further south than it is at present. The break-up of the massive supercontinent Gondwana was well underway, and Australia was in the process of separating from Antarctica, from west to east, so that the west coast of Tasmania was at the end of a long embayment that stretched across from the southwest of Western Australia. At this time the world was in the grip of a greenhouse climate and there was no ice on Earth. This was the result of an extremely high atmospheric carbon dioxide level and the consequent greenhouse effect, and also the disposition of the southern continents which forced ocean currents to circulate water from equatorial latitudes down to very high southern latitudes and back again (Figure 1A). While oceanic water was near the Equator, the sun was often directly overhead, and solar radiation which was relatively high warmed the water as it still does today. This warm water was then circulated down to polar latitudes taking an enormous amount of energy with it, and warm oceanic water was a feature of polar latitudes at this time. This warm water contributed to high evaporation rates and so rainfall was extremely high, and we have evidence that this was the case all through the year. These warm and extremely wet conditions led to rainforest being the dominant vegetation globally at this time. At the high southern latitudes of southern Australia there were massive river systems, and lining them were diverse and complex rainforests, most similar to those that grow today in far north Queensland and Papua New Guinea.

These rainforests left behind fossilised remains at several locations across southern Australia and in most cases they are associated with extremely high energy braided river systems. Occasionally small backwaters would form in these rivers, and in amongst the normal deposition of coarse sand there are lenses of fine grained siltstone where channels were cut off from the main flow of the river. In amongst these siltstones the litter from the surrounding forests was preserved: usually pollen, leaves and twigs, but occasionally

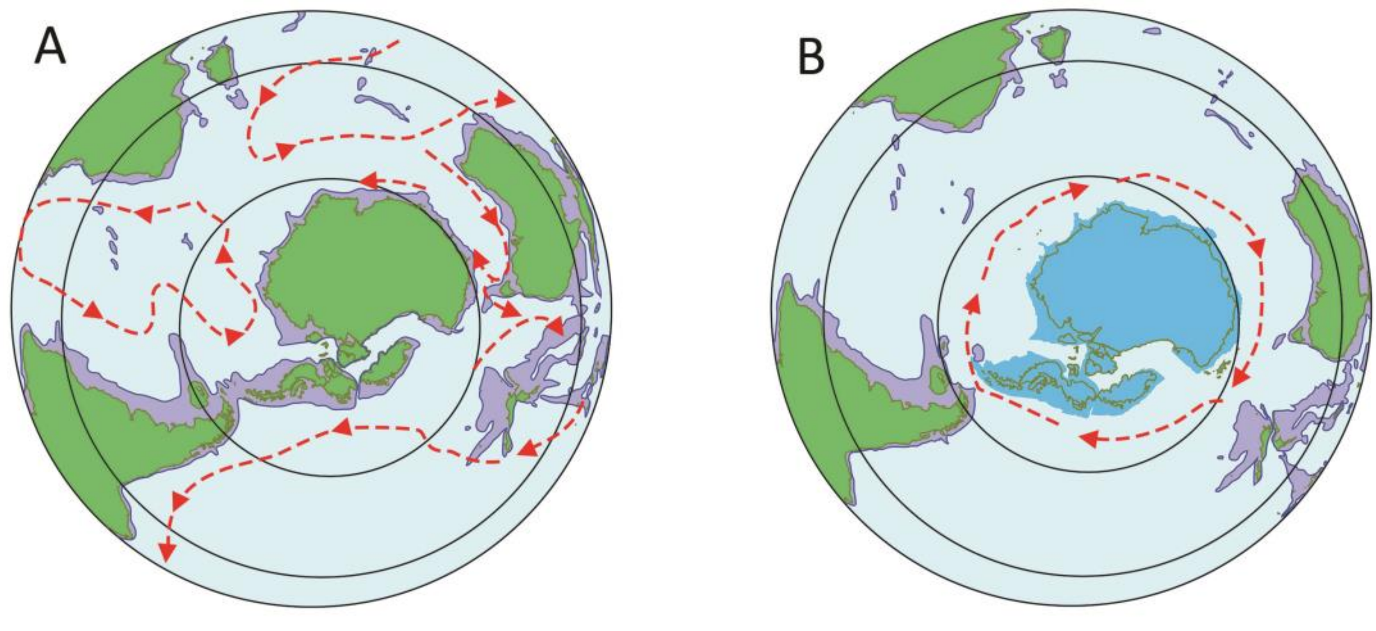

Figure 1. Continental reconstructions of the Southern Hemisphere showing the probable ocean currents about 34 million years ago (**A**) and 16 million years ago (**B**). Ocean currents are indicated in red and ice-free land is shown in green. Modified from Cantrill, D.J. and Poole, I. (2012) The Vegetation of Antarctica through Geological Time. Cambridge University Press.

seeds and fruits and even flowers. These fossils are often exquisitely preserved (Figure 2), and provide an astonishing record of a past time when climatic conditions and the vegetation were extraordinarily different from today.

Around 35 million years ago dramatic events initiated major changes to the Australian environment. The atmospheric carbon dioxide levels began to drop leading to a gradual global climate change and Australia and South America moved towards completion of their separation from Antarctica. In Australia's case this was the beginning of a long northward journey through about 20° of latitude at an average rate of about 7 cm per year. This journey continues today and will do so well into the future.

When Australia and South America separated from Antarctica, ocean currents changed dramatically and the Circum-Antarctic current came in to place. This major current moved massive amounts of oceanic water around Antarctica, keeping the water at high latitudes for long periods of time (Figure 1B). While this water still received radiation from the sun, it was always from a low angle in the sky meaning that the incoming radiation had to pass through a lot of atmosphere before reaching the ocean. In the process, much of the incoming radiation was absorbed by molecules in the atmosphere or was reflected back out into space. Hence much less radiation reached the sea surface than occurs at the Equator and as a result the oceans cooled significantly at high latitudes. Eventually this led to snow fall on Antarctica, and since snow has high reflective properties, even less of the sun's energy was absorbed and it became even colder. Over tens of millions of years this resulted in a massive Antarctic ice cap that today is kilometres thick over much of the continent.

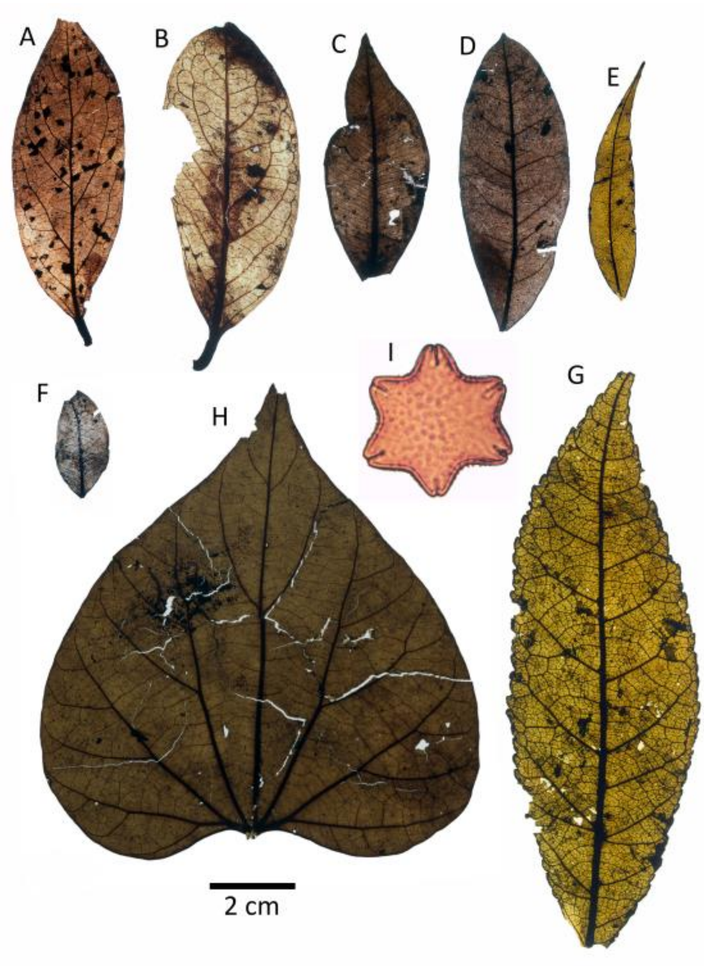

Figure 2. Mummified leaves from the Victorian Anglesea deposit (**A-G**) and the southern New South Wales Nerriga deposit (**H**). A pollen grain for the dominant genus *Nothofagus* (**I**) is also shown. These leaves are typical of those found in subtropical and tropical rainforests today. They include typical rainforest families such as Lauraceae (**A** ,**B**), Myrtaceae (**C, F**) and Menispermaceae (**H**). All these leaves are about 42-45 million years old.

One consequence of this growth in the ice sheet is that much of the water vapour was stripped out of the atmosphere and Australia began to dry significantly. In the last 20-25 million years Australia has transformed from a wet, rainforest-dominated continent to a largely arid continent with rainforest remnants clinging to some of the coasts, largely dominated by desert, grasslands, shrublands and eucalypt-dominated forests. That transition is in part captured in our fossil record, and we can see the impact of increasing dryness with the fragmentation and destruction of the earlier extensive rainforests (Fig. 3).

The demise of the rainforests was exacerbated by the fact that Australia is an old and flat continent, and much of the soil present is extremely low in nutrients, particularly phosphorus. It is well known that plants growing in low phosphorus soils are not able to produce as much living cell tissue and they are often characterised as having small, tough leaves, a shrub-like form, and extensive root systems that have evolved to extract as much phosphorus as possible from the soil. This is a plant form that is known as scleromorphy. Many Australian plants had evolved a scleromorphic life form even when rainforests were extensive, and when the climate began to dry these plants were ideally placed to dominate the vegetation, because the characters they had evolved to deal with low soil nutrients just happened to also be good for dealing with low water availability (Figure 3). This is a process known as pre-adaptation or exaptation. Major Australian plant groups like the Proteaceae (*Banksia*, *Grevillea*, *Hakea* etc) and the Casuarinaceae (*Casuarina*, *Allocasuarina*) are familiar examples of major Australian plant groups that followed this evolutionary pathway. As the climate dried even further, these plants and many others evolved to become even better adapted to the dry conditions. Plants that are especially well adapted to dry environments are known as xeromorphic and there are countless examples of this in the Australian vegetation today.

As the climate continued to dry, the litter produced by plants no longer decayed quickly and began to accumulate in the landscape. This, along with the developing hot and dry summers in southern Australia provided one of the prerequisites for fire to become an important part of the landscape— fuel that is dry enough to burn. The other prerequisite, an ignition source, must have been provided by dry lightning strikes, since from about 20 million years ago fire has been an increasingly obvious part of the Australian landscape.

Some Australian vegetation remains extremely poorly adapted to fire and cannot survive it in any obvious way; rainforest and alpine vegetation are good examples. However, many Australian plants have one of two major adaptations to fire. They are either **fire resistant**: they can survive fire and remain present on the site afterwards, either because of vegetative recovery or seed germination, e.g. Figure 3A; or they are **fire promoters**: they produce high quantities of volatile oils and stringy or ribbon bark that can carry burning embers well beyond the fire front and start new fires. Many Eucalypts are excellent at this, e.g. Figure 3D.

The fossil record suggests that some fire adaptations have been present in Australian plants for 70 million years or more, suggesting that while Australia was mostly rainforest 45 million years ago, there must have been some drier vegetation where fire resistance was an important trait.

Nevertheless, the resulting Australian vegetation that we live with today is remarkably different from the extensive and diverse rainforests that clothed southern Australia 45 million years ago. This has genuinely been one of the great natural experiments in climate change that the Earth has experienced. We continue to undertake research on the fossils that we have in our collections, but there is room for much more research to be done and we are constantly seeking new fossil deposits to work on. Fossils usually form where there is a large amount of water in the environment, so our collections are biased towards vegetation growing in wet places. We are always on the look out for new locations, so if you come across plant remains in sediment anywhere, we will be interested in seeing what you have found.

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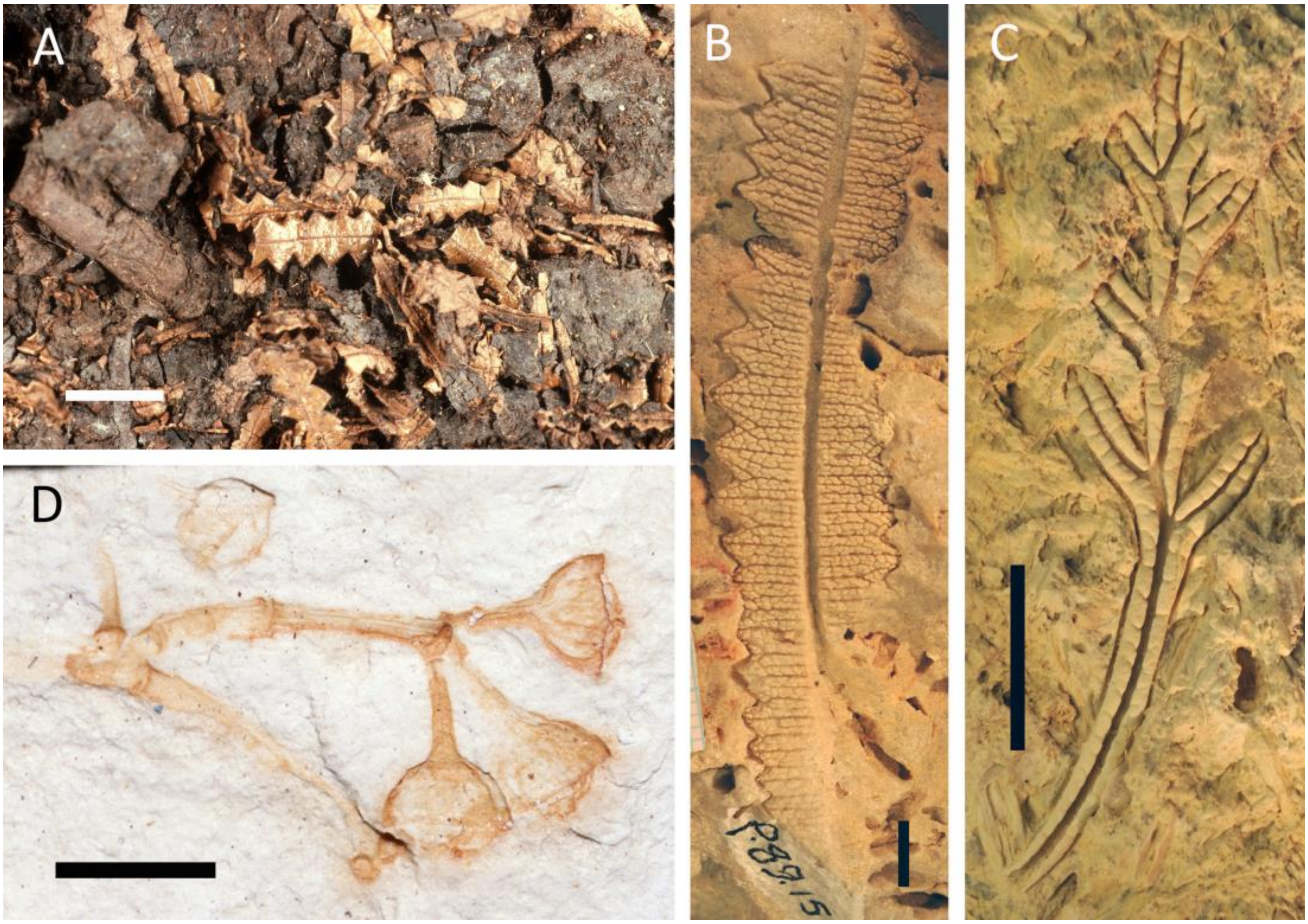

Figure 3. Fossils representing drier vegetation in Australia. **A**. *Banksia* leaves from the Latrobe Valley coal in Victoria, about 20 million years old. **B** and **C**. Proteaceae fossils as moulds in hard silcrete from southwestern Australia. These leaves show clear xeromorphic adaptations. The age is uncertain, but probably around 30-40 million years old. **D**. Impressions of eucalypt fruits (gumnuts) from the Warrumbungle Mountains in New South Wales, about 12-16 million years old. Scale bars all = 1 cm.

LINKING BIODIVERSITY, SOIL MICROBIOMES AND HUMAN HEALTH

Craig Liddicoat

Introduction

Around the world more and more people are losing contact with nature, largely due to the rapid growth of cities, land degradation and declining biodiversity. At the same time we are witnessing epidemics in non-communicable diseases including allergies, autoimmune, and chronic inflammatory diseases. High rates of anxiety and depression are also associated with urban living. Now a growing number of medical researchers suspect these trends may be linked.

There is also growing evidence linking green space exposure with a range of beneficial health outcomes, including cardiovascular, mental health and 'all cause' mortalities. Because there is such a diversity of health benefits associated with nature contact, some researchers suggest that a broad, nonspecific physiological pathway of action, or a multiplicity of pathways, or a combination of these, may be present. However, until recently there has been a lack of knowledge of potential beneficial mechanisms that might connect green space with such diverse human health outcomes.

I became interested in researching environmental influences on human health following a presentation by Professor Phil Weinstein at the South Australian NRM Science Conference in 2014. After a couple of meetings with Phil, which included discussing my background in soil science and data analysis, and the potential for health influence via the 'hygiene hypothesis' (see below), my interest was sparked to try a postgraduate research degree in this area. Under Phil's supervision, and also Professors Michelle Waycott and Peng Bi, I started on an after-hours basis in March 2015. To keep up with challenging work, I changed to 'full-time' status (still juggling part-time work) between mid-2017 to mid-2019. I have now completed my PhD in October this year. It has been a huge amount of work, but also a fascinating journey. In this article I present a background and overview of outputs and findings from my PhD.

Natural environments and human health

Environmental microbial communities (or microbiota) and their genetic material (microbiomes) are suspected to form part of the connection between environments and human health. Environmental microbiota have the potential to interact and influence our own human microbiota (e.g. via skin, airway, gut), and the immune system, both of which are central to supporting our health. Indeed, exposure to microbial diversity from the environment provides key inputs to train and educate the immune system, especially from an early age.

The 'biodiversity hypothesis' suggests that a lack of exposure to environmental microbial diversity may impede the development of a normal healthy immune system, and therefore contribute to the rise in many immune-related, non-communicable diseases in modern societies.

Another key concept is the notion that we may have microbial 'Old Friends', or key species, that play particular roles in supporting our health. However, we may be missing contact with these Old Friends in our modern biologically depauperate and overly-clean environments.

These ideas represent an advancement from the earlier 'hygiene hypothesis' – which originally suggested that greater exposure to childhood infections may provide an immune-boosting benefit. Now there is an increasing appreciation of the immune-training potential of the huge array of micro-organisms that are found in the environment. The thinking is that, similar to a body builder building strength and fitness by 'working out', our immune system would build fitness through exposure to both microbial diversity and key species (Old Friends).

Pathways between microbes and human health

We can imagine that nature would work in many ways. We can conceptualise at least four pathways or mechanisms through which microbes from the environment can help boost our immune fitness. Firstly, microbes from the environment can help build immune memory via the production of antibodies. Secondly, they can add to the protective microbial communities that line our skin, airway, and gut. Here, greater diversity becomes important to keep any particular organism in check. Thirdly, environmental microbes actively participate in immune signalling. For example, in the gut certain immune cells can reach through gaps between the cells of the gut lining to sample microbes from inside the gut. These immune cells recognise molecular patterns in the microbes being sampled and trigger a cascade of immune signals that can either lead to defensive inflammation (which is needed against pathogens), or trigger tolerance responses to organisms that are normally harmless. A fourth mechanism is that microbes can produce metabolites or by-products with beneficial properties. For example, butyrate is a by-product produced by microbes from the breakdown of plant material, which is also a key energy source for the cells that line the gut. These mechanisms suggest there is a biological connection, via microbes, between our environment and our health. It should also be noted that immune signalling pathways from key regions such as the gut can influence the entire body.

These mechanisms of beneficial health influences from environmental microbes represent a shift in thinking from our historic view of medical microbiology. In hospitals with immunocompromised patients, antimicrobial washes and antibiotic treatments, it might be perceived that 'the only good microorganism is a dead microorganism'. Media

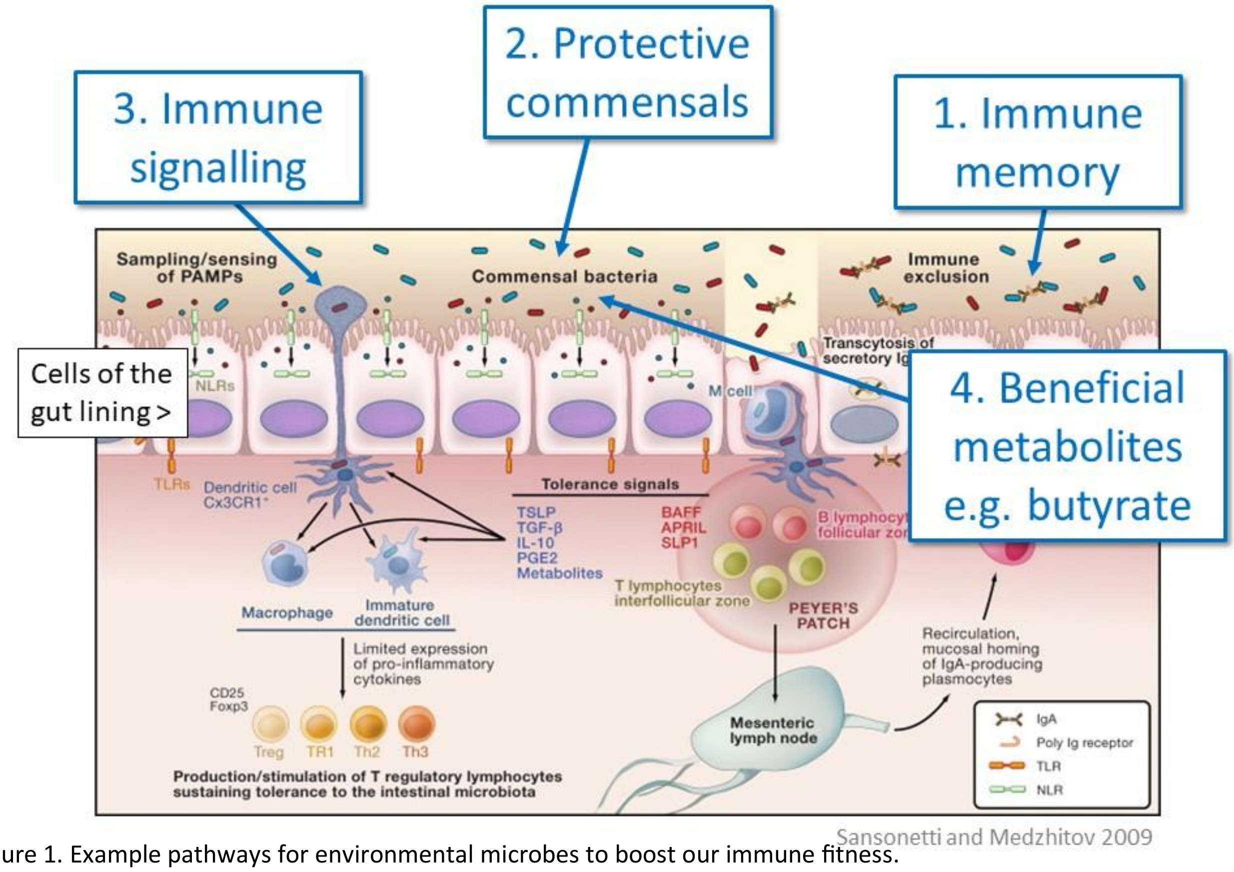

Figure 1. Example pathways for environmental microbes to boost our immune fitness.

advertising suggests we should also take this approach in our homes, with antimicrobial hand washes and kitchen wipes.

Environmental microbes

However, to foster a normal healthy immune system we should probably take quite a different attitude to environmental microbes. We have co-evolved with a diverse array of microorganisms, and proponents of the Old Friends mechanism suggest that our immune system and perhaps other parts of our physiology are likely to have learnt to borrow or depend on functions that can normally be provided by microorganisms commonly encountered in the environment.

In a 2016 review paper I presented a hypothetical argument that beneficial health influences will be most likely when exposure to key species (Old Friends) and microbial diversity are combined. Too much exposure to any particular microbe is likely to be detrimental, for example resulting in infection. By definition, no or very low exposure to an Old Friend will be insufficient to support health. If there is some intermediate (e.g. low to moderate) exposure capable of providing the appropriate immunomodulatory input, then this should be balanced by a diverse community capable of controlling any potential overgrowth or pathogenic behaviour of the particular Old Friend.

Influences on human microbiota and immune-related health outcomes

Lifestyle, culture and environment have been shown to influence microbiota and immune-related health outcomes. Children who grow up in cities tend to have higher rates of allergies, compared to children who grow up on farms. Also, different farming approaches can have different influences. The Amish who farm with more basic practices including use of manures experience fewer allergies than the Hutterites who farm using more industrial practices and fertilisers. The gut microbiota of traditional African tribes-people is very different to modern city-living Europeans.

Armed with the idea that biodiversity and associated microbial diversity might somehow support improved health outcomes, at the start of my PhD I wanted to test if there was support for this idea within existing available national public health and environmental mapping datasets. To do this I performed two nationwide spatial environmental epidemiology studies.

Respiratory health study

The first study [1], examined respiratory health (i.e. respiratory disease hospital admissions in local government areas): considered as a conspicuous theme in the context of environmental microbiomes – because we are breathing in airborne microbiomes (aerobiomes). I compiled a large number of candidate explanatory environmental and social mapping variables. This included map layers representing greenness (based on satellite NDVI data), as well as a custom-made 'vegetation diversity' layer. I built the vegetation diversity layer by calculating the Shannon diversity index based on mapped vegetation classes (from National Vegetation Information System [NVIS] data) within a 3 km radius and placing this value in the centre 250 m x 250 m raster cell; then repeating this several million times over the entire Australian continent. Needless to say, it was handy to run through a programming script. All data were then averaged back to local government areas.

I ran a modelling algorithm which selected only those variables deemed useful to explain the outcome of respiratory disease hospital admissions. It was notable that the variables of vegetation diversity and species richness (obtained from the Atlas of Living Australia, ALA) were identified as highly important and beneficial – i.e. associated with fewer hospital admissions. The key message from this study is that biodiversity matters! That is, it's not just any green space, but the quality of green space that appears to be important. It was also notable that these biodiversity-themed layers were derived from an accumulation of biological survey data (via NVIS and ALA).

Soil microbial diversity

In the next study [2], I figured that the largest source of microbial diversity in natural environments would likely be in soils. Therefore, I wanted somehow to include soil as a candidate explainer. Since I was also keen to explore the possible influence of environments as a general indicator of population immune fitness, I considered available data for rates of infectious and parasitic disease as the health outcome variable.

Mapping of soil microbial diversity was not available, however, I was able to establish that soil cation exchange capacity (CEC, for which mapping was available) provided a useful proxy indicator of microbial diversity. CEC represents the sum of positively charged major nutrients stored in soils, but can also reflect the complexity of habitat for soil microbes in the form of clay and organic matter content (clay and organic matter content generally have a surface negative charge). With the inclusion of several other environmental (including climatic) and social variables, soil CEC emerged as a dominant explainer of the variation in infectious and parasitic disease rates.

Among the poorest areas, people living in and around soils with high CEC experienced a dramatic lowering of infectious disease hospital admissions. Seemingly, having higher soil CEC (i.e. typically high soil microbial diversity) in the surrounding environment was able lower disease rates to levels comparable with the wealthiest areas. By contrast, poor areas with low CEC (i.e. low microbial diversity) soils, had the highest rates of infectious and parasitic disease. I also built multivariable models to explain the patterns of disease rates and was able to show that including knowledge of the soil quality (CEC) could explain an additional 7.5% of the variation, and therefore improve disease rate predictions in unseen areas not previously encountered in model-training.

These studies supported the idea that biodiversity and soil microbial diversity might be providing some health-boosting effect just based on spatial proximity and the type of ambient environment. In order to explore a more mechanistic understanding I was convinced of the need to delve into microbiome analyses. This was a new field for me and represented a steep learning curve.

Soil microbiomes in a revegetated landscape

In a third study [3], I was able to collaborate with another group of researchers doing cutting-edge work with genomics in the field of restoration ecology. Nick Gellie and Martin Breed and others in Andy Lowe's lab had performed a study in the Adelaide Hills where they showed that soil microbial communities shifted progressively with revegetation from degraded/cleared land towards soil microbiome profiles corresponding to remnant native vegetation (Dr Andy Lowe is the Director, Food Innovation Theme, School of Biological Sciences, University of Adelaide).

I started examining Nick's Adelaide Hills study data as a means of becoming familiar with microbiome data analysis techniques, but then began on a path of customised data analysis, looking for ways to identify indicator bacteria at a fine taxonomic resolution (at genus level or as close as possible). I was looking for indicator bacteria that might be favoured at either end of the disturbed vs. mature-biodiverse spectrum. At the end of a complex analysis, a simple message seemed to emerge. If we feed soils simple and unreliable food (i.e. in disturbed/degraded soils) this will favour more opportunistic bacteria. The nature of these opportunists – e.g. including taxa that are fast-growing, short-lived, generalist-feeders, which can lay dormant between periods of rapid growth – means that disturbed/degraded soils are likely to contain more potential pathogenic bacteria. On the other hand, soils under mature biodiverse vegetation will tend to favour bacteria that are slower-growing, long-lived and prefer a specific niche food resource, or are adapted to take advantage of complex food sources.

To validate these findings, I brought in data from over 200 publicly-available soil microbiome samples from across Australia, assigning these to either a 'disturbed' or 'natural' class based on the aboveground vegetation and land use. I found that the indicator bacteria (i.e. top 10 increasing and top 10 decreasing) from the Adelaide Hills study displayed largely similar differential abundance patterns between the disturbed vs. natural soils. When I checked for human-associated bacteria, the disturbed/degraded soils contained more *Legionella*, *Enterobacter*, *Pseudomonas* and *Clostridium*. These genera are known to contain important respiratory and intestinal pathogens that affect humans. (Figure 2)

Mouse study linking biodiversity, soils and improved health

Over the last couple of years of the PhD, I had formed the opinion that we would need to perform a mouse study to make real progress in understanding potential microbiota-mediated mechanisms that may link biodiversity and soils to improved health outcomes. Many factors influence the central role of the gut microbiome in supporting our health, including genetics, natural or caesarean birth, early feeding and social contact, diet, antibiotic use, sleep, stress, amongst others. Without large numbers of study participants, it was necessary

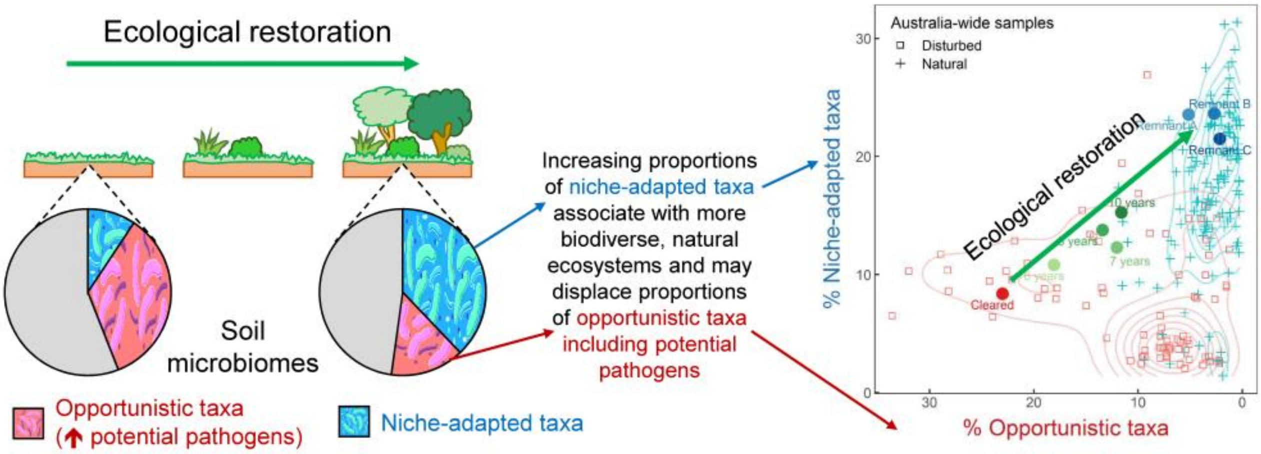

Figure 2. Restoration of biodiverse vegetation produces a shift in soil microbiomes, reducing opportunist and potential

to control many of these factors in order to isolate a potential environmental effect. Using a mouse model system was the most practical way to achieve this.

Researchers elsewhere have shown that mouse immune biomarkers and gut microbiota change after exposure to particular sources of soil microbial diversity and to particular environmental microbes. However, they have typically used unrealistic exposures, including large quantities of soil, forced feeding and injections to simulate environmental exposures. A primary objective of our mouse study [4] was to see if exposure to natural ambient microbial diversity, in the form of trace-levels of soil dust, could cause a change in mice gut microbiota. Our treatments comprised no soil dust (control), low biodiversity soil dust and high biodiversity soil dust. Low biodiversity soils (from cleared land with low aboveground macro-diversity) had low microbial diversity. High biodiversity soils came from nearby remnant native vegetation and had high microbial diversity.

The mouse study would not have been possible without the support and input of a team including key collaborators Martin Breed (who also provided core funding for the study), and Mark Hutchinson (from the Adelaide Medical School and Director of the Australian Research Council Centre of Excellence for Nanoscale BioPhotonics), who provided time from some of his post-doctoral researchers to train and support our study team. Staff from Laboratory Animal Services at the University of Adelaide also provided essential support. For the daily mouse work over a nearly 10-week period, followed by DNA lab work for several weeks, our core team comprised of Harrison Sydnor, Chris Cando-Dumancela, Romy Dresken and myself. After the microbiome sequencing data came back from the Australian Genome Research Facility (AGRF), I spent several more weeks analysing the data to develop a clear picture of what had happened.

In the mouse study, fans were run over the soil samples for 2 hours on and 2 hours off for 7 weeks to create light dust exposures. Exposing the mice to only trace-level dust was a risky venture, as we didn't know whether we would get a result. But surprisingly, we were able to provide the first evidence that gut microbiomes could be influenced by ambient natural airborne microbes in the form of trace-levels of biodiverse soil dust.

Among many recognised mouse intestinal bacteria, there was a bacteria that increased during the experiment that warranted attention: this was a soil-derived, anaerobic, spore-forming butyrate-producer. With knowledge that our gut is dominated by spore-forming bacteria (as this is a survival mechanism for bacteria that need to spend at least some time

Figure 3. Example sites for sampling source soils from SA Water Mt Bold Reservoir Reserve. The upper panel shows a high biodiversity soil sampling location, while the lower panel shows a low biodiversity soil sampling location.

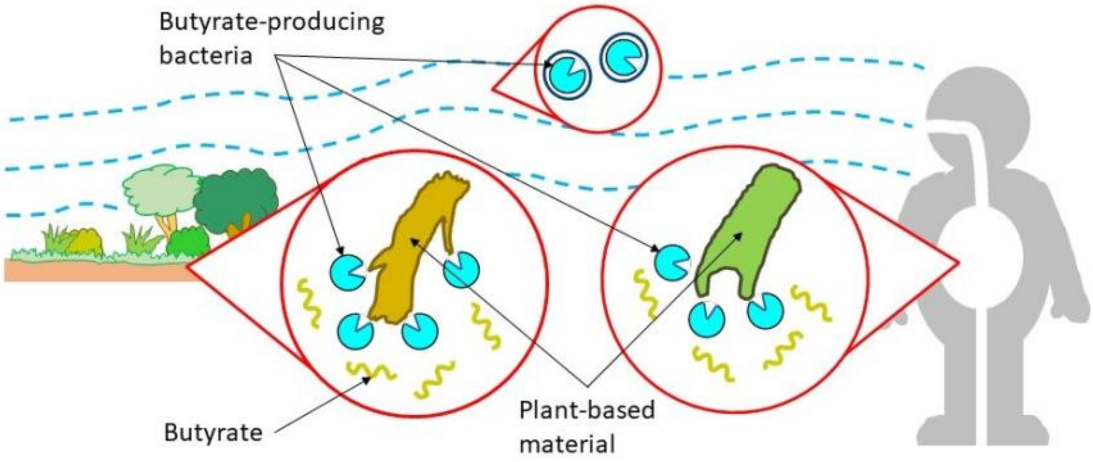

Figure 4. Exposure to naturally high biodiversity soils may favour the supplementation to the gut microbiome of spore-forming, anaerobic, butyrate-producing bacteria – with potential for gut health and mental health benefits.

outside in an aerobic environment) this seemed to be a type of bacteria that might be at home in both the gut and the soil. Bacteria involved in butyrate production are special, because butyrate is a breakdown product of plant matter (both in the gut and in soil) **and also** a key product that supports gut health and mental health in humans. Importantly, we found over the experiment that the butyrate-producing bacteria increased the most in abundance in the guts of the high biodiversity treatment mice. We then tested for anxiety-like behaviour in the mice, and found that increasing relative abundance of the soil-derived butyrate-producing bacteria correlated with reducing anxiety-like behaviour in the most anxious mice.

Therefore, our study points to a new, potentially broadly-applicable mechanism, capable of linking biodiversity to gut health and mental health, via butyrate-producing bacteria. Our study suggests these bacteria can be blown by wind from soils in biodiverse green space (in their protected, sporulated form) and are capable of supplementing the gut microbiome (as depicted in Figure 4). Elsewhere, studies show that soil microbes commonly represent a dominant proportion of the aerobiome (air-borne biome).

Other mouse studies suggest that poor diets can cause the extinction of key gut bacteria within individuals and within generations. However, our work suggests that certain key bacteria, such as the butyrate-producer we identified, may be resupplied from exposure to biodiverse green space and their soils. This is a mechanism that should work amongst humans and many other animals exposed to biodiverse areas and their soils and aerobiomes.

Collaboration and health cost savings

The findings of my PhD add to the arguments justifying increased collaboration between health and environmental management agencies around the world. Indeed, such collaboration is something that the World Health Organisation and UN Convention on Biological Diversity would like to see. In many places, health agencies are increasing budgets to address ballooning health care costs. Often this might occur at the expense of other government spending, for example on the environment.

Future work should aim to provide an **economic valuation** for the contribution of biodiversity to health improvement and disease prevention. Even if a small percentage of the spending on health could be avoided through creating healthier, more liveable and microbiome-conscious environments, this might free up valuable resources to help preserve, enhance, and restore biodiversity, and help build awareness of the importance of biodiversity among the wider community.

Studies for further reading (also refer to references therein):

1. Liddicoat et al. 2018. Landscape biodiversity correlates with respiratory health in Australia. *Journal of Environmental Management* 206, 113-122.
2. Liddicoat et al. 2018. Ambient soil cation exchange capacity inversely associates with infectious and parasitic disease risk in regional Australia. *Science of The Total Environment* 626, 117-125.
3. Liddicoat et al 2019. Can bacterial indicators of a grassy woodland restoration inform ecosystem assessment and microbiota-mediated human health? *Environment International* 129, 105–117
4. Liddicoat et al, 2020. Naturally-diverse airborne environmental microbial exposures modulate the gut microbiome and may provide anxiolytic benefits in mice. *Science of the Total Environment* 701, 134684

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OBSERVATIONS ON SEG'S EXPEDITION TO INNES NATIONAL PARK

Olly Cirocco

It's a crisp morning, and the remainder of last night's frost still stings my nose and cheeks as I jump out of the ute and traipse into the mallee scrub with my group. We enter the site eagerly, letting bright pink ribbons guide our way forward. Dried twigs and leaf litter crunch loudly beneath our feet, and prickles of native shrub poke and prod at our skin and clothes. Every now and then, one of us will brush our hands over our body, hoping no ticks have managed to lodge themselves on to our skin. Bright sunlight streams in through eucalyptus branches and bears down on our necks. Over the soft murmur of conversation, the occasional warble of a Mallee Western Whipbird may be heard in the distance. I get straight to work checking the mesh funnel traps for any critters that may have snuck in. As I shake each funnel, I watch the others poke around in pitfall traps and weave their way through dense vegetation. Although everyone is concentrating hard on the work at hand, there can be no denying the sheer joy that fuels our actions. With every smear of dirt and swat of a fly, with every lizard discovery and cheeky joke shared, we grow closer as a group, not only with each other but with the land itself.

* * *

Throughout the expedition in Innes National Park, it became even more apparent to me that the 'divide' between humans and nature is far smaller and insubstantial than we may initially be led to believe. Never before have I seen a group of people become so excited by the sight of a native orchid in bloom, or the prospect of a malleefowl nest potentially nearby. With every critter we uncovered in our traps, we exclaimed in delight, gushing (and I am particularly guilty here) "Ohhh look at his lovely colouring!" or "Off you go little bugger!"

The data we were able to obtain through our captures and recordings of native animals was, of course, of great importance to the Great Southern Ark Project. However, it also allowed those of us involved the opportunity to embrace the more primitive, down to earth aspects of our being. I personally found myself constantly comparing the behaviours exhibited by the different animals to the behaviours we exhibit as humans. Lizard species such as the Southern Slider (*Lerista dorsalis)* would wriggle and worm its nearly legless body through your fingers in a desperate attempt to escape the moment it was picked up. Contrastingly, the Shrubland Morethia Skink (*Morethia obscura*), would perch quite stiff and still on your finger and would remain so for a little while after being let go. These responses reflect quite perfectly the way different human individuals may respond to fear or danger; some of us fight or run away with everything in us, whilst others freeze and hope for the best.

On a larger scale, the group dynamics and relationships of SEG functioned like its own little ecosystem. Every night when we returned to the hall for dinner in dribs and drabs, I watched as the natural systems that governed our field subjects were mimicked in the humans I dined with.

We all worked together as a team, and despite our differences I found myself forming friendships and meaningful connections with the people around me. We laughed, swapped stories, shared what we'd learned that day, and bonded over the thing that had brought us all together in the first place; our natural world. Being able to connect with people was definitely one of the highlights of this trip for me, and served as a welcome reminder that no amount of effort is too small when it comes to caring for our precious ecosystems.

* * *

My name is Olly Cirocco, and I am currently in my final year at the University of Adelaide, majoring in Anthropology and Ecology. I am particularly interested in the rehabilitation of natural systems, and the ways in which people and nature can interact in positive ways. I am constantly seeking opportunities where I can volunteer my assistance, so feel free to contact me at ollycirocco@gmail.com.

Western Pygmy Possum (*Cercartetus concinnus*)

MANAGING WATER FOR THE ENVIRONMENT — AN OVERVIEW FROM THE COMMONWEALTH ENVIRONMENTAL WATER OFFICE

Bill Matthews

What is water for the environment?

"Water for the environment" (also known as environmental flows) can be a complex concept to grasp. While it could mean any water in a river or wetland that benefits the environment, when we talk about water for the environment we are referring to water that has been specifically allocated to help improve the health of our rivers. This water is managed by state and federal environmental water holders who decide when and where to release water for the environment into rivers and wetlands to support the plants and animals that live, feed and breed in them.

Why do we need it?

Many of our rivers and wetlands across the Murray-Darling Basin have been highly modified to provide water for towns, industry and food production. Instead of water flowing naturally through the landscape, water is now captured in dams and weirs, and then extracted or diverted for a range of human uses. In some rivers, more than half of the water that would have naturally flowed is removed each year. In 2013-14, 69% of all inflows in to the Murray-Darling Basin were extracted for agriculture.

Extracting this volume of water has fundamentally altered the way our rivers function, with changes to the volume, frequency, duration and seasonality of flows. This in turn has negatively affected the health of our river, wetland and floodplain ecosystems. As a result many rivers are not able to function as they would naturally. This means it is necessary to actively manage how water flows through rivers.

Water reform and the creation of the Commonwealth Environmental Water Holder

The first formal allocation of water for the environment was made in 1967. This was soon followed by other allocations of water for the environment, but always in relatively small volumes. The Millennium Drought then highlighted a critical need for a more comprehensive environmental watering strategy. Extended drought between 1997 and 2010 caused significant environmental damage across the whole of the Murray-Darling Basin. In South Australia, the lack of water flowing to wetlands resulted in the widespread die back and decreased health of mature river red gum and black box trees, important sources of food, shelter and nesting sites for a wide variety of native species. Water levels in the Lower Lakes plummeted to 1.1 meters below sea level. This exposed acid sulphate soils, turning the lakes into the equivalent of battery acid. Water ceased to flow past the barrages and out to the Coorong and Murray Mouth. The lack of fresh water resulted in a significant increase in salinity levels, with the Coorong's southern lagoon reaching levels more than three times that of sea water.

In response to the Millennium Drought, Australia embarked on a world-leading water reform process, with the aim of achieving an environmentally sustainable level of water use in the Murray-Darling Basin. This included returning 2,750 gigalitres (GL) of water to the environment and the creation of

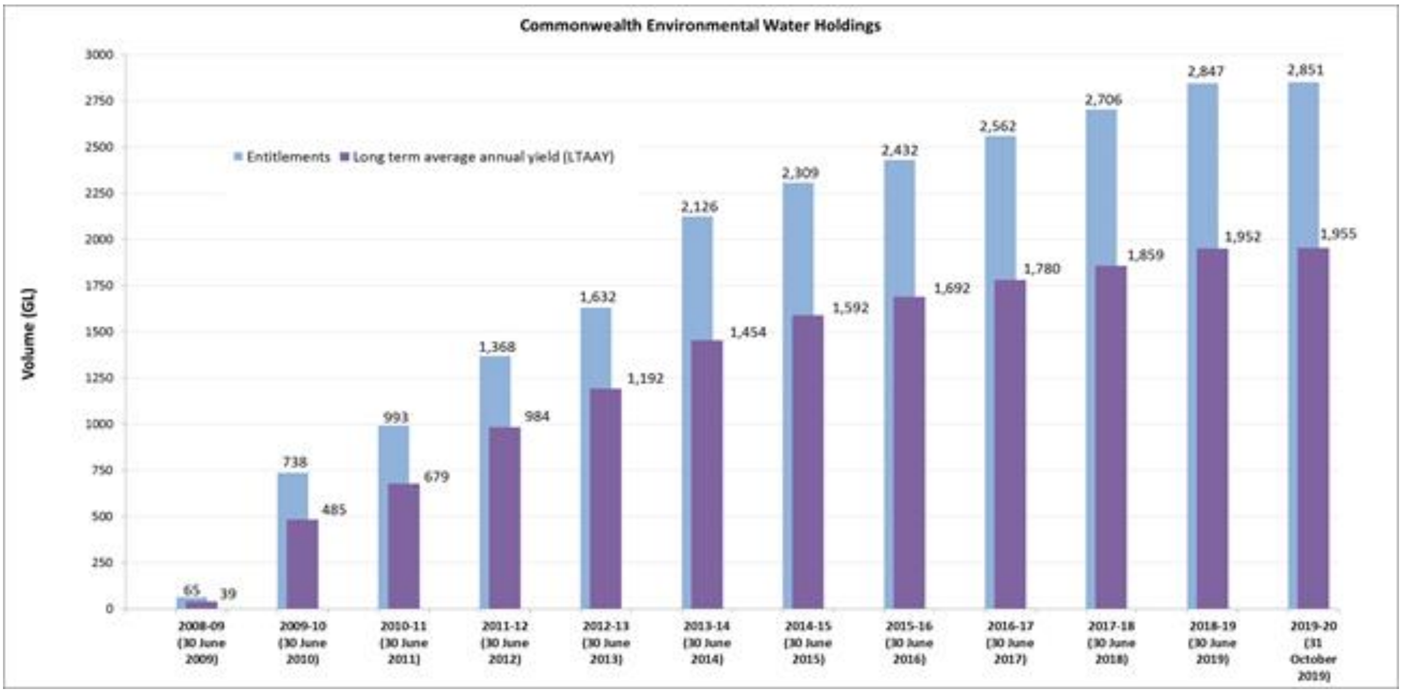

Figure 1: Commonwealth Environmental Water Holdings from 2008-2019. The Entitlement is the potential volume of water and the Long Term Average Annual Yield (LTAAY) is the actual volume of water.

the Commonwealth Environmental Water Holder (CEWH) to manage this water.

The CEWH is a Commonwealth independent statutory position established by the *Water Act 2007* to manage Commonwealth environmental water holdings to protect or restore environmental assets in the Murray-Darling Basin. The CEWH leads and is supported by the Commonwealth Environmental Water Office (CEWO), a division of the Australian Government Department of the Environment and Energy.

The CEWH manages a portfolio of water for the environment (Figure 1). This water was acquired through the Australian Government's investment in water-saving infrastructure and strategic water license purchasing throughout the irrigation districts of the Basin.

Decisions on how to use Commonwealth Environmental Water

The CEWH's decisions about the best use of this water are guided by the *Water Act 2007*, the Murray-Darling Basin Plan 2012, science, and a range of other planning documents. Obligations on the use of Commonwealth environmental water under the Water Act ensures efficient and effective use of the available water to deliver the best environmental outcomes, while benefitting river communities.

To achieve these obligations, the CEWH strategically decides when and where to use water to achieve environmental objectives, including:

- Providing river flows that support improved water quality for the environment;
- Connecting rivers to low lying floodplains to maintain food chains and support fish movement;
- Filling wetlands that support native fish, birds and other native animals; and
- Supporting the recovery of the environment following drought and building resilience in preparation for the next drought.

These decisions are made with state environmental water holders across the Basin to achieve the best environmental outcomes. They are informed by advice and feedback from river operators, First Nations people, scientists, local site managers, advisory groups, irrigation corporations and landowners.

The CEWH may also decide to save a portion of water to be carried over for use in the following year. The purpose of this is to create a short-term storage of water for the environment, essentially being saved to be used at the start of the new water year when opening water allocations might still be very low. This helps to kick-start ecosystem processes during the winter/spring months.

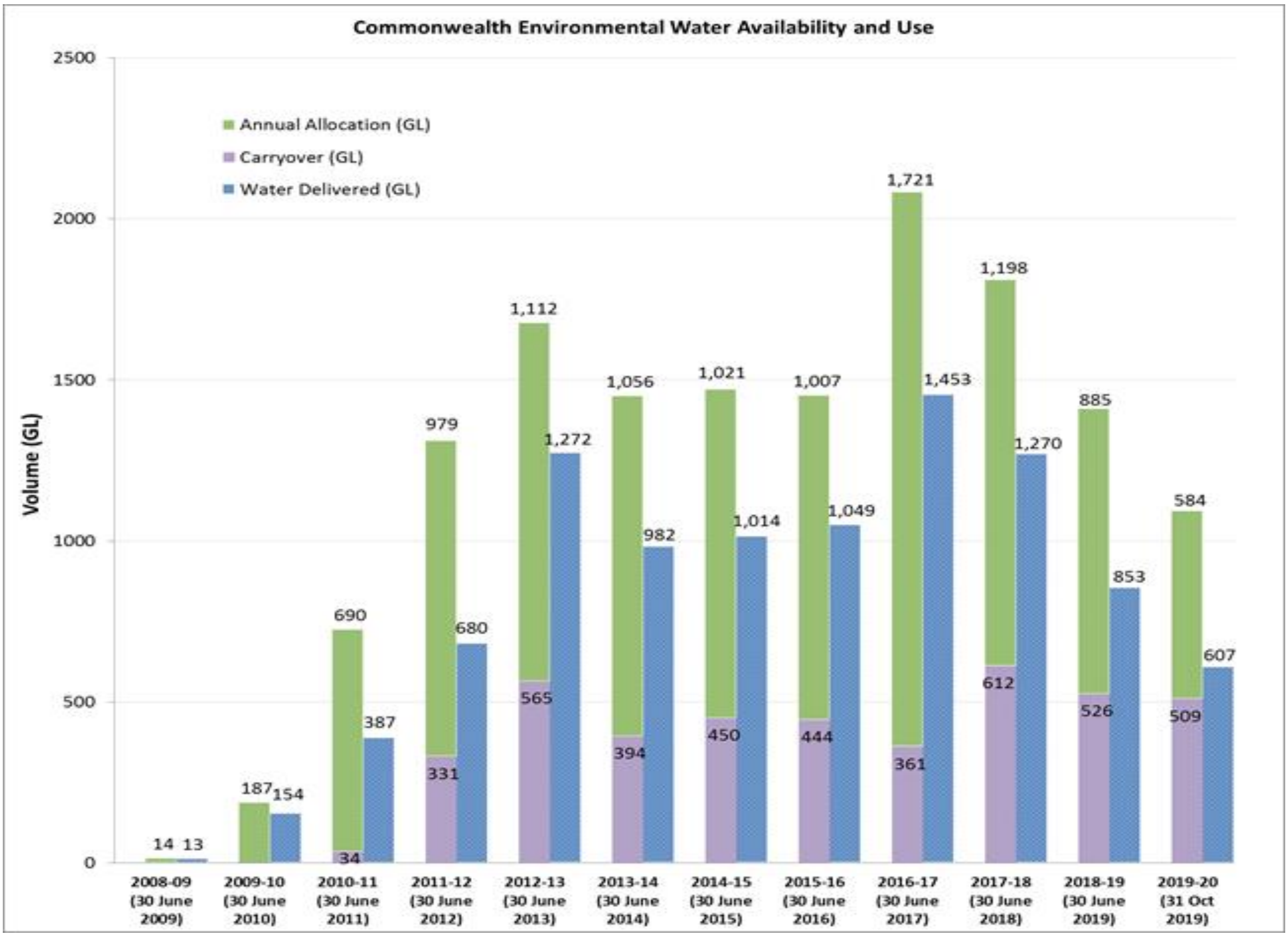

Figure 2: Water availability and water use as at 30 June each year from 2011-12 to 2019-20.

The CEWH can also sell water if at least one of two conditions is met:

1. Environmental watering objectives have been met and either: the water cannot be carried over; or keeping the allocations is likely to result in future allocations being reduced.
2. Environmental outcomes can be improved by selling water allocations and using the proceeds to purchase water and/or invest in environmental activities.

These activities could include:

- Improving water delivery methods to get the water where it is needed;
- Getting the best ecological outcomes;
- Supporting listed species and communities; and
- Incorporating local and cultural knowledge and values.

How much Commonwealth Environmental Water is there?

As of October 2019, the Commonwealth Environmental Water Holder manages an average volume of water of about 1,950 GL (Figure 1). Since the CEWH began delivering water in 2008, over 9,694 GL of Commonwealth Environmental Water has been delivered to over 20,000 kilometers of rivers across 1 million square kilometers (Figure 2). This represents about 14% of all water extracted from the Basin on average.

Contrary to common perception, the CEWH manages only a fraction of the water that once flowed through the Basin, making it vitally important that water for the environment is managed strategically to maximise environmental outcomes.

Results so far

A major focus of the CEWH has been the development of an effective monitoring program for water for the environment. Operational monitoring is conducted for every watering action to identify volumes delivered, timing, duration, location, flow rates and river heights. In conjunction with watering action monitoring, the Commonwealth has invested over $80 million in monitoring and research and now has a decade of robust scientific results (Figure 3). The management of water delivery is continuously adapted based on these scientific results to ensure the best environmental outcomes are achieved.

The results are showing improvements in river environments across the Basin, but there is also still more work to be done.

While Commonwealth water for the environment has achieved beneficial environmental outcomes, like other water users, the CEWH is limited by lower water availability during dry times. During drought, sites in critical condition and home to endangered species are most likely to receive water for the environment. These sites provide refuge for plants and animals so they can bounce back when the drought breaks - a bit like a farmer maintaining their breeding stock.

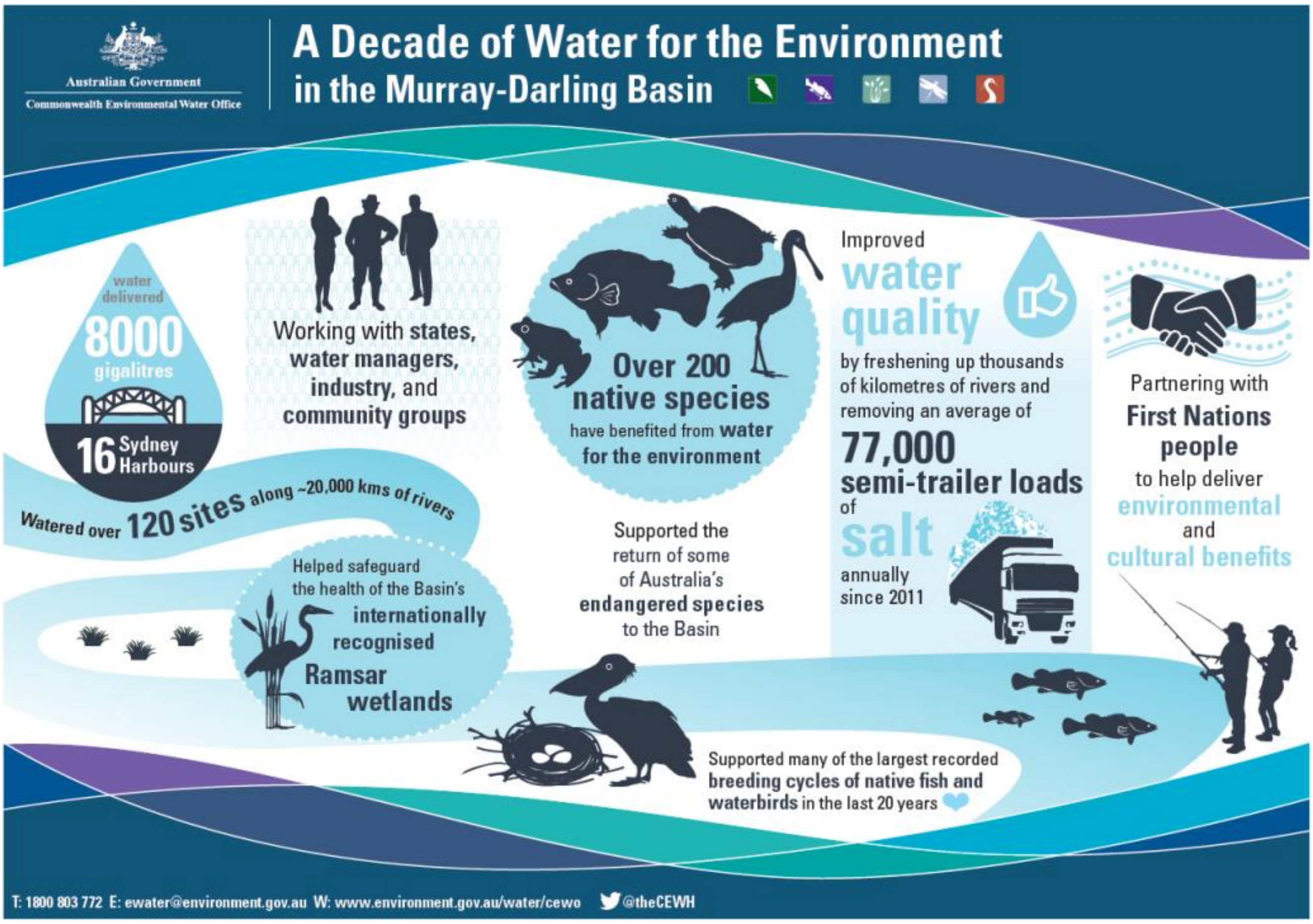

Figure 3: Key outcomes from a decade of water for the environment delivery (published September 2018)

Water for the environment can also improve water quality, decreasing the chance of algal blooms and hypoxic black water and reduce exposure of acid sulphate soils, avoiding the death of native plants and animals and the impacts on agriculture and communities. Australia was unprepared for the severity of the millennium drought, which had devastating effects on the environment, as well as farmers, irrigators and other water users across the Basin. As Australia grapples with another significant drought period, the primary focus of the CEWH is to build up the resilience of water dependent ecosystems.

The 50-year evolution of water management in the Murray-Darling Basin has led to one of largest and most significant river restoration programs in the world. It has required high-levels of government investment, both in the initial recovery of water for the environment and in its subsequent management. However, the significant change in the share of water available to the environment in the Basin has had immediate, observable benefits. While restoring the health of the Basin is a long and ongoing journey, water for the environment can help us achieve a healthy and sustainable river basin for the enjoyment of future generations.

More information can be found at: https://www.environment.gov.au/water/cewo/about-commonwealth-environmental-water

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The condition of Banrock station wetland before and after Commonwealth Environmental Water

A cohort of Black bream from 2017-18 that successfully recruited by flows supported by Water for the Environment.

YORKETOWN AREA SCHOOL VISIT TO SEG'S INNES BIODIVERSITY SURVEY

Angus Nowlan

I am a year 10 student at Yorketown Area School who has always loved and shown great interest in science and the natural environment. I have lived in Marion Bay for 13 years and because of that I have spent basically my whole life in and around Innes National Park, running through the bushes and looking at all the different animals.

Even though I have spent so much time in the park, I still learnt a lot from the biodiversity camp when a number of Year 10 students joined a SEG biodiversity survey of the Innes National Park. Like all the different species of reptiles that I had never even known were down here, such as the yellow–faced whip snake, the bull skink and others.

On the first day we talked for about two and a half hours about what was going on and why we were doing this, and then we were separated into groups and were taken to the catching sites. At every location we split into three groups: one to check each set of traps (pitfall, Elliott and funnel traps). Because we arrived at night, we were just resetting the Elliott's. We didn't see anything on the first day apart from a couple insects, but it was all useful to the team.

The next day we got up early just in case anything had been caught in the Elliott traps, since we had to release captures asap so they didn't cook in the heat of the day. We saw a lot more creatures on the second day, like pygmy possums, snakes, skinks etc.

The things I enjoyed most about the trip was being outside in the national park running amuck whilst also doing some research to help find out what is down here. Checking the pitfall traps was another one of my favourite things to do, as they were the main traps that caught anything.

I think the re-wilding project that is being attempted on Southern Yorke Peninsula is a great idea, and that it will have a lot of benefits to the environment and the species within the area. However, no matter how hard they work, it seems to me that they will never be able to get rid of all the pest species, i.e. rabbits, foxes, cats and other non-native animals within the park.

Thank you to all the SEG workers and volunteers for hosting Yorketown Area School students – we welcome the opportunity to do it again in the future.

The Yorketown Area School students entering a trap site

Yorketown Area School students checking a pitfall trap with SEG volunteers. The author is third from the left

MINNAWARRA BIODIVERSITY PROJECT — SPRING 2019

JANET FURLER

The Spring survey was held from Monday 30th September to Friday 4th October. We were due to start on Saturday 27th, but a series of cold nights caused the delay. We were still able to do most of the preparation over the weekend, with all sites open before lunch on Monday. I did wonder at that stage how we might manage the work at the end of the week but our outstanding volunteers kept on keeping on and it all worked like clockwork. Thank you all.

39 people visited, some for half a day, some camping for the whole week, giving 432 hours of energy and interest.

Our total mammal catch was 101 individuals, with only one feral house mouse (*Mus musculus*). There were 19 *Antechinus flavipes* (yellow-footed antechinus), 48 *Rattus fuscipes* (bush rats) and 33 *Rattus lutreolus* (swamp rats). 45 of these were recaptures from previous surveys. After Greg Johnston's comment during his talk at the AGM about 5-10% of tagged birds being recaptured, our 45% is quite impressive. However, we do have a much less mobile population! The proportion last spring was 47% but only 19 individuals in total. The proportion of recaptures last autumn (April 2019) was 13% (20 out of 151).

The 101 mammals were caught a total of 214 times, with a couple of keen or hungry *A flavipes* mums turning up for all 8 rounds. We record how many pouch young they have, including no young but still lactating. For the first time we had a record going from no young to one – an enterprising pup had a long lunch. This number of catches gives a good chance for some of the participants to learn how to handle the animals, although they are given rats to practice on, rather than the *Antechinus* with young. Once again we didn't see any bandicoots. I will get cameras out to see if they have got wary of the traps, or don't like the peanut paste and oats, or have moved on.

The non-mammal catch numbered 24, consisting of 17 garden skinks (*Lampropholis guichenoti*), 4 three-toed earless skinks (*Hemiergis decresiensis*) with pretty orange bellies, 2 common froglets (*Crinea signifera*) and one grey shrike-thrush (*Colluricincla harmonica*) in a cage trap.

The numbers could well be an indication of a reasonable season, including spring rains, for which we (as farmers) are extremely grateful. As Christmas rapidly approaches we are only just losing the green feed and not hand feeding stock yet. The down side is that the dry feed is ready to burn, but we cross our fingers.

The next survey is from Friday 10th April to Tuesday 14th April 2020. This is over Easter.

thefurlers@gmail.com

SEG is very grateful to our corporate sponsor Microchips Australia for its support to the Minnawarra Project.

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